There Are Phase Transitions That Need Neither Temperature nor Attraction: What Controls Them Is Density

— For grains of powder or sand, lifting one grain by its own diameter costs 1.902994×10^{4} times the thermal energy at 0.01 mm and 1.902994×10^{12} times at 1 mm, so temperature does nothing — the separator is whether the control variable is temperature or density — [Paper 674]

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— From thinking to syncing. —

Abstract

A phase transition is naturally thought of as something brought on by changing the temperature. But powder and sand set solid without temperature or attraction.What controls that transition is counted, through the ratio to thermal energy and through packing fractions.No new theorem or law is claimed. First, temperature does nothing in this system——lifting a glass sphere in water by its own diameter costs 1.902994×10^{4} times the thermal energy at 0.01 mm, 1.902994×10^{8} times at 0.1 mm and 1.902994×10^{12} times at 1 mm (Section 2). **Second, that boundary is the edge of the colloidal window——at a diameter of 1 micrometre the same ratio is only 1.902994. Below it thermal motion acts (Paper 673); above it lies the subject of this paper** (Section 2). **Third, and this is the core. What controls it is density——random close packing at 0.64 against face-centred cubic at 0.740480 differ by 0.100480: the same spheres, packed differently, differ by a tenth** (Section 3). **Fourth, in terms of voids the difference is larger ——the void fractions are 0.360000 against 0.259520, a ratio of 1.387179: the same spheres in the same volume leave nearly forty per cent more empty space** (Section 3). **Fifth, the number of contacts needed to set is fixed by dimension——without friction, balancing forces and moments requires 4 contacts in the plane and 6 in space** (Section 3). **Sixth, the separator is whether the control variable is temperature or density——cooling does not jam it; raising the density does** (Section 4). **Keywords**: jamming, random close packing, packing fraction, granular material, phase transition, isostatic.

Scope of this paper (scope note): **No new theorem or law is claimed——random close packing, the packing fraction of the face-centred cubic lattice, isostatic contact numbers and the name "jamming" are all standard (Bernal and Mason 1960, Liu and Nagel 1998).No phase diagram is drawn——the full jamming diagram in temperature, density and stress is not treated; only the density axis is examined.The relation to the glass transition is not discussed——how a transition set by time relates to one set by density is not the subject, and no judgement of common or distinct root is made.Friction is not included——grains with friction have different isostatic numbers; only the frictionless case is counted.Flow is not treated——clogging in silos, avalanches and granular flow are not the subject.Representative values are used——random close packing at 0.64 is an experimental representative value and moves with the method of packing.Relation to earlier papers**: **Paper 673 counted, through the sedimentation length, the window of sizes in which thermal motion beats gravity, and put the boundary for silica in water in a vessel 0.1 m tall at a diameter of 17.3855 nm——this paper counts what sets the phase outside that window, where heat does nothing.Paper 365 treated the Brazil-nut effect and stated that packing itself, random or close, was not its subject——this paper takes that seat.**What is added is **deriving the ratio of lifting work to thermal energy by diameter to show that temperature does not act**, **showing that its boundary coincides with the edge of the window of Paper 673**, **setting the two packing fractions and their void ratio side by side**, and **placing the separator on temperature against density**.

1. Notation and the Question

Setting: **spheres of diameter d and density difference $\Delta\rho$ lie piled together. The work of lifting one grain by its own diameter is compared with the thermal energy $k_B T$.**

$$\frac{W}{k_B T} = \frac{\Delta\rho\,(\pi/6) d^3\, g\, d}{k_B T}$$

This ratio grows as the fourth power of the diameter. Where it is large, no change of temperature moves the grains.How tightly they are packed is measured by the packing fraction.

Question: **when powder or sand sets solid, what is the control variable?**

2. The Side Where Temperature Does Nothing

Computation 2.1: **for glass spheres in water (density difference 1500 kg/m^3, 293.15 K), the lifting work and its ratio to the thermal energy were derived.**

diameter	lifting work	ratio to thermal energy
0.001 mm	7.702125×10^{-21} J	1.902994
0.01 mm	7.702125×10^{-17} J	1.902994×10^{4}
0.1 mm	7.702125×10^{-13} J	1.902994×10^{8}
1 mm	7.702125×10^{-9} J	1.902994×10^{12}

At 1 micrometre the ratio is only 1.902994; at 1 mm it is 1.902994×10^{12}.

> **Observation 2.2**
>
> the boundary is the edge of the window of Paper 673.Below the size where the ratio is near one, around a micrometre, thermal motion moves the grains; that is the side Paper 673 treats——above it, temperature is not available as a control variable. Sand neither packs nor unpacks on being warmed or cooled.

3. Density Sets the Phase

Computation 3.1: the packing fractions and void fractions of two packings were derived.

packing	packing fraction	void fraction
random close packing	0.64	0.360000
face-centred cubic (ordered)	0.740480	0.259520

The packing fractions differ by 0.100480 (a ratio of 1.157001) and the voids by a ratio of 1.387179.

Computation 3.2: raising the packing fraction leaves, to random close packing, 0.140000 at 0.50, 0.090000 at 0.55, 0.040000 at 0.60, 0.010000 at 0.63 and 0.000000 at 0.64.

Computation 3.3: without friction, the contacts needed to balance forces and moments, the isostatic number, are 4 in the plane and 6 in space.

Observation 3.4

this is the core: the control variable is density.As the packing fraction rises, the grains come to confine one another and the assembly begins to answer shear like a solid. Neither temperature nor attraction is needed for this——what is needed is only that the contacts reach the isostatic number.

4. The Separator

Observation 4.1

the separator is whether the control variable is temperature or density.A transition brought on by temperature is undone by restoring the temperature; one brought on by density is undone by lowering the density——the one word “setting” divides by which variable was moved.

Observation 4.2

beside Paper 673.Paper 673 counted the window in which thermal motion beats gravity and showed that what falls inside it is called a colloid——this paper is the outside of that window: the same model of spheres, with contacts rather than heat as the partner that acts.

Observation 4.3

what is not said.Neither the full phase diagram, nor the relation to the glass transition, nor the case with friction is treated, and 0.64 is an experimental representative value——what is shown is that a phase can be set without temperature, and that there the control variable is density.

5. Roll Call and Closing

1. **1.902994×10^{12} at 1 mm** (Computation 2.1): **temperature does nothing.**
2. **1.902994 at 1 micrometre** (Computation 2.1): **the edge of the window of Paper 673.**
3. **face-centred cubic 0.740480** (Computation 3.1): **ordered packing.**
4. **random close packing 0.64** (Computation 3.1): **an experimental value.**

5. **a difference of 0.100480** (Computation 3.1): **a tenth apart.**
6. **void ratio 1.387179** (Computation 3.1): **nearly forty per cent.**
7. **0.010000 left at 0.63** (Computation 3.2): **just before jamming.**
8. **isostatic numbers 4 and 6** (Computation 3.3): **fixed by dimension.**
9. **neither temperature nor attraction** (Observation 3.4): **the core.**
10. **temperature or density** (Observation 4.1): **the separator; Paper 673.**

Closing: **A phase can change without moving the temperature.For grains, lifting one by its own diameter costs 1.902994×10^{4} times the thermal energy at 0.01 mm and 1.902994×10^{12} times at 1 mm, so temperature is not a control variable at all.What acts is density: random close packing at 0.64 against face-centred cubic at 0.740480, a difference of 0.100480, and a void ratio of 1.387179——what setting requires is only that the contacts reach the isostatic number, 4 in the plane and 6 in space.The separator is whether the control variable is temperature or density.Placed among the earlier papers——this is the outside of the window counted in Paper 673: the same spheres, with contacts rather than heat as the partner.To be honest——neither the phase diagram nor friction is treated, and 0.64 is an experimental representative value.**

References

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